

What is claimed is:

1. A micro-optical device comprising:

a reflective movable micro-mirror connected with comb finger electrodes

5 and springs via a shuttle beam;

a set of suspended springs connected with said shuttle beam and with one end anchored onto a substrate;

a comb drive actuator consists a set of movable comb finger electrodes suspended on a substrate and connected with said shuttle beam, and a set

10 of stationary comb finger electrodes anchored on said substrate; and

a shuttle beam movable with respect to the stationary portion of said substrate in response to operation of said comb drive actuator, thereby said micro-mirror is moved by this said shuttle beam; characterized in that,

15 a portion of said springs is thinner than the rest portion of microelectromechanical structures of said elements on the perpendicular out-of-plane direction to said substrate of the device.

2. The micro-optical device as claimed in claim 1, wherein the micro-mirror

of said micro-optical device stays in an initial position without external

20 electrical load, thereby the incoming optical signals from one channel of the

input ports transmit toward the reception optical fiber of one channel of the output ports; the set of movable comb drive electrodes which are connected with a movable shuttle beam move toward the stationary comb drive electrodes due to the electrostatic force between said two sets of comb drive electrodes when the electrical load is applied to the comb drive actuator, the micro-mirror connected with said shuttle beam move to the second stable position and stays at this position, thereby the incoming optical signals from one channel of the input ports transmit toward said micro-mirror, then said incoming optical signals being reflected toward the reception optical fiber of another channel of the output ports;

therefore the input optical signals can transmit forward from one channel of input ports to an initial output channel when said micro-optical device maintains at its initial state without external applied electrical load, and when said micro-optical device under operation with external applied electrical load, said micro-optical device can switch said optical signals from one channel of input ports to a specified channel of output ports other than the initial output channel.

3. The micro-optical device as claimed in claim 1, wherein the micro-mirror of said micro-optical device stays in an initial position without external

applied electrical load, thereby the incoming optical signals from one channel of the input ports transmit forward said micro-mirror, and being reflected toward the reception optical fiber of one channel of the output ports; and, the set of movable comb drive electrodes which are connected with a movable shuttle beam move toward the stationary comb drive electrodes due to the electrostatic force between said two sets of comb drive electrodes when the electrical load is applied to the comb drive actuator, the micro-mirror connected with said shuttle beam move to the second stable position and stays at this position, thereby the incoming optical signals from one channel of the input ports transmit toward the reception optical fiber of one channel of the output ports without incident onto said micro-mirror; thus said micro-optical device can make said incoming optical signals from one channel of input ports be reflected by said micro-mirror toward a specified channel of output ports when said micro-optical device maintains at its initial state without external applied electrical load; and the input optical signals can transmit from one channel of input ports toward one channel of output ports due to these optical signals being reflected by said micro-mirror when said micro-mirror has been moved by comb drive actuator to the second stable position.

4. The micro-optical device as claimed in claim 1, wherein the fiber of input channel and the fiber of output channel are located and aligned along with the light beam transmission axis, and the micro-mirror of said micro-optical device is located in the spacing between the fiber end of input channel and the fiber end of the output channel, and the light intensity of optical signals in transmission is controlled and attenuated in terms of blocking a portion of the transmitted light beam, where the operation of blocking a portion of the transmitted light beam and thereby the attenuation range is determined by the position of said micro-mirror regarding to the actuation of said movable comb drive under external electrical load.

5. The micro-optical device as claimed in claim 1, wherein the fiber of input channel, the fiber of output channel, and the micro-mirror of said micro-optical device are located and aligned in a geometric layout configuration where the input light beam from the fiber of input channel reflected by said micro-mirror toward the reception fiber of the output channel; thereby all the input optical signals from the input fiber reflected by said micro-mirror toward the output fiber at the initial state of said optical device, and the attenuation range is determined by the position of said micro-mirror regarding to the actuation of said movable comb drive

under external electrical load.

6. The micro-optical device as claimed in claim 1, wherein the fiber of input channel, the fiber of output channel, and the micro-mirror of said micro-optical device are arranged and aligned in a geometric layout configuration where all the light intensity of input optical signals from the input fiber are not coupled into the output fiber at the initial state of said optical device, and a portion of the input light intensity start to be coupled into the output fiber due to said micro-mirror moving to the corresponding position where said portion of the input light beam is reflected by said micro-mirror toward the output fiber, when the comb drive is actuated to move said micro-mirror under external electrical load; thereby the attenuation range is determined in terms of said micro-mirror position.

7. The micro-optical device as claimed in claim 1, wherein the multiple input channels of fiber optics, the multiple input channels of fiber optics, and a plurality of reflective micro-mirror of said micro-optical device are located and aligned in a geometric layout configuration where the input light beam from one of the multiple input channels of fiber optics reflected more than one time by said reflective micro-mirror then transmitted toward one of the multiple output channels of fiber optics; thereby all the input optical signals

being reflected more than one time by said micro-mirror toward the output channels; wherein the fiber optics comprise the optics integrated and assembled with the fibers and waveguides to achieve desired collimated light beam.

- 5      8. The micro-optical device as claimed in claim 1, wherein the set of springs consists four symmetric allocated folded-beam springs that these springs comprise at least one pair of compressive structures located on one side of said device regarding to center of device; and the spring constant along with the perpendicular in-plane direction to the moving direction of said set of
- 10      springs is increasing as the moving displacement increased; therefore said micro-optical device is more robust to the side instability of finger electrodes in longer actuation displacement.
- 15      9. The micro-optical device as claimed in claim 1, wherein said set of springs consists a pair of normal folded-beam springs with U-shaped-bridge joint, and a pair of compressive folded-beam springs located in a symmetric manner; and the spring constant along with the perpendicular in-plane direction to the moving direction of said set of springs is increasing as the moving displacement increased; therefore the micro-optical device is more robust to the side instability of finger electrodes.

10. The micro-optical device as claimed in claim 1, wherein the finger electrode shape of said comb drive actuator of said micro-optical device is a kind of shape with an oblique angle thereby the generated force output from said comb drive actuator is enlarged for device designs and applications need large actuation force.
11. The micro-optical device as claimed in claim 1, wherein a clip type latch mechanism comprises a grip structure formed on the substrate of said micro-optical device to clamp said shuttle beam via the friction force formed at the contact interface of the clamped location between grip structure and shuttle beam; thereby said micro-optical device can maintain its status at certain state without electrical power consumption when said clip type latch is used to clamp said shuttle beam.
12. The micro-optical device as claimed in claim 1, wherein the mirror surface of said micro-mirror of said micro-optical device is smoothed by applying the silicon etching solution to reduce the surface roughness that is formed during said DRIE process for making the micro-mirror sidewall from said silicon substrate.
13. The micro-optical device as claimed in claim 1, wherein the mirror surface of said micro-mirror of said micro-optical device is smoothed by adopting

the (110) oriented silicon substrate as the initial substrate in conjunction with a post DRIE wet etching step in the silicon etching solution, thereby a silicon sidewall of smooth (110) facet is formed to be the mirror surface and the surface roughness of the just DRIE etched mirror is reduced.

5      14. The micro-optical device as claimed in claim 1, wherein the mirror surface of said micro-mirror of said micro-optical device is smoothed by a post DRIE oxidation step of the DRIE etched micro-mirror structure of said micro-optical device, thereby a silicon sidewall of smooth surface is formed.

10      15. The micro-optical device as claimed in claim 1, wherein the device substrate of said micro-optical device is covered and sealed by a lid to protect the fragile MEMS elements including the micro-mirrors, comb drive electrodes, suspended springs, micro-optics, and MEMS actuators.

15      16. The micro-optical device as claimed in claim 1, wherein the flow channels and trenches are formed on said substrate of said micro-optical device to let the fluidic materials and melted metals flow through inside said channels and trenches during the alignment, assembly, sealing, and packaging process; thereby the fragile MEMS elements will avoid from the damage caused by said fluidic materials.



17. A micro-optical device comprising:

a reflective movable micro-mirror connected with comb finger electrodes and springs via a shuttle beam;

5 a set of suspended springs connected with said shuttle beam and with one end anchored onto a substrate;

a comb drive actuator consists a set of movable comb finger electrodes suspended on a substrate and connected with said shuttle beam, and a set of stationary comb finger electrodes anchored on a substrate;

10 a shuttle beam movable with respect to the stationary portion of said substrate in response to operation of said comb drive actuator, thereby said micro-mirror is moved by this said shuttle beam;

15 a clip type latch mechanism comprises a grip structure formed on the substrate of said micro-optical device to clamp said shuttle beam via the friction force forming at the contact interface of the clamped location between grip structure and shuttle beam; thereby said micro-optical device can maintain its status at certain states in an analog controllable manner without electrical power consumption when said clip type latch is used to clamp said shuttle beam.

18. A micro-optical device comprising:

a reflective movable micro-mirror connected with comb finger electrodes and springs via a shuttle beam;

a set of suspended springs connected with said shuttle beam and with one end anchored onto a substrate;

5 a comb drive actuator consists a set of movable comb finger electrodes suspended on a substrate and connected with said shuttle beam, and a set of stationary comb finger electrodes anchored on a substrate;

a shuttle beam movable with respect to the stationary portion of said substrate in response to operation of said comb drive actuator, thereby  
10 said micro-mirror is moved by this said shuttle beam;

a clip type latch mechanism comprises a grip structure formed on the substrate of said micro-optical device to clamp said shuttle beam via the friction force forming at the contact interface of the clamped location between grip structure and shuttle beam; thereby said micro-optical device  
15 can maintain its status at certain states in an analog controllable manner without electrical power consumption when said clip type latch is used to clamp said shuttle beam.

a portion of said springs is thinner than the rest portion of microelectromechanical structures of said elements on the perpendicular

out-of-plane direction to said substrate regarding to said device.

19. A micro-optical device comprising:

a reflective movable micro-mirror connected with comb finger electrodes

5 and springs via a shuttle beam;

a set of suspended springs connected with said shuttle beam and with one end anchored onto a substrate;

a comb drive actuator consists a set of movable comb finger electrodes suspended on a substrate and connected with said shuttle beam, and a set of stationary comb finger electrodes anchored on a substrate;

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a shuttle beam movable with respect to the stationary portion of said substrate in response to operation of said comb drive actuator, thereby said micro-mirror is moved by this said shuttle beam;

a clip type latch mechanism comprises a grip structure formed on the substrate of said micro-optical device to clamp said shuttle beam via the electrostatic force forming between the gap between two side electrodes of grip structure when the two electrodes attract to each other, and come to contact with shuttle beam, where the electrodes of grip arm are coated with insulating materials and isolated from the shuttle beam; thereby said

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micro-optical device can maintain its status at certain states in an analog controllable manner without electrical power consumption when said clip type latch is used to clamp said shuttle beam.

20. A micro-optical device comprising:

5 a reflective movable micro-mirror connected with comb finger electrodes and springs via a shuttle beam;

a set of suspended springs connected with said shuttle beam and with one end anchored onto a substrate;

10 a comb drive actuator consists a set of movable comb finger electrodes suspended on a substrate and connected with said shuttle beam, and a set of stationary comb finger electrodes anchored on a substrate;

a shuttle beam movable with respect to the stationary portion of said substrate in response to operation of said comb drive actuator, thereby said micro-mirror is moved by this said shuttle beam;

15 a clip type latch mechanism comprises a grip structure formed on the substrate of said micro-optical device to clamp said shuttle beam the electrostatic force forming between the gap between two side electrodes of grip structure when the two electrodes attract to each other, and come to contact with shuttle beam, where the electrodes of grip arm are coated

with insulating materials and isolated from the shuttle beam; thereby said micro-optical device can maintain its status at certain states in an analog controllable manner without electrical power consumption when said clip type latch is used to clamp said shuttle beam.

5 a portion of said springs is thinner than the rest portion of microelectromechanical structures of said elements on the perpendicular out-of-plane direction to said substrate regarding to said device.

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